ESTIMATION OF FALL CHUM SALMON ABUNDANCE ON THE UPPER TANANA RIVER USING MARK RECAPTURE TECHNIQUES, 1998

by

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ABSTRACT

Mark-recapture techniques were used to produce population estimates of fall chum salmon (*Oncorhynchus keta*) in the Tanana River for the fourth consecutive year in 1998. Chum salmon were captured and tagged using a fish wheel located on the right bank (facing downstream) of the Tanana River, and recaptured in two fish wheels located on opposing banks approximately 76 km upriver from the tagging wheel. All fish wheels operated 24 hours per day unless interrupted by mechanical problems. All healthy chum salmon captured at the tagging wheel from 17 August through 5 October 1998 were marked with spaghetti tags and released. Fish were divided into two categories: "day fish," tagged with orange tags and caught between 08:00 and 20:00, and "night fish", tagged with yellow tags and caught between 20:00 and 08:00. Night fish remained in the live box for up to twelve hours, while the maximum time a day fish remained in the live box was four hours. A total of 1,146 day fish and 655 night fish were tagged. Tag recovery wheels operated from 16 August through 6 October, 1998. The right and left bank recovery wheels caught a total of 1,282 and 1,962 chum salmon respectively, of which 81 were first-time recaptures. Tag deployment and recovery operations ceased as a result of icing conditions, although catch levels indicated that the chum salmon run was continuing. The mean migration rate between the tag deployment and recovery wheels was 28.7 km per day for day fish and 30.8 km per day for night fish. The final in-season Bailey model population estimate was 62,014 (SE = 6,556) chum salmon past the tagging wheel site. The marked proportion in the recovery wheels varied temporally, indicating that we had not tagged in proportion to abundance. Consequently, a temporally stratified model was implemented post-season. The final estimate using the Darroch model was 62,384 (SE = 12,076) chum salmon past the tagging wheel site.

KEY WORDS: Yukon River, Tanana River, *Oncorhynchus keta,* chum salmon, mark-recapture, population size, escapement, migration rate, run timing

INTRODUCTION

The Yukon River drainage is the largest in Alaska (854,700 km^2), comprising nearly one-third the area of the entire state. Five species of Pacific salmon return to the Yukon River and its tributaries and are utilized in subsistence, personal use, commercial and sport fisheries. The Tanana River is the largest tributary of the Yukon River. It flows northwest through a broad alluvial valley for approximately 700 km to the Yukon River at the village of Tanana, draining an area of 115,250 km^2.

Chum salmon *Oncorhynchus keta* return to the Yukon River in genetically distinct summer and fall runs (Wilmot et al. 1992, Seeb et al. 1995). Summer chum salmon begin to enter the Yukon River in early May and fall chum salmon begin to enter in mid-July. Fall chum salmon migration typically peaks around mid-September in the Tanana River drainage. Migration continues into early October, with spawning taking place from mid-October through November, primarily in areas where upwelling ground water prevents freezing. Fall chum salmon are larger on average than summer chum salmon, have a higher oil content, and are considered a more desirable food source in the Upper Yukon and Tanana Rivers.

Yukon River fall chum salmon are an important fishery resource in the subsistence and personal use fisheries, particularly in the upper portions of the river. The Tanana River drainage is considered to be a major producer of Yukon River fall chum salmon and contributes significantly to the various in-river fisheries. The most recent five-year (1992-1997) average total harvest of fall chum salmon in the Tanana River is approximately 49,272 fish, or approximately 21% of the entire Yukon River drainage average for the same years (Bergstrom et al. 1998).

The Alaska Department of Fish and Game (ADF&G) has management responsibility for fisheries in the Alaska portion of the Yukon River drainage. For management purposes, the drainage is divided into a total of 6 districts and 10 subdistricts. The Tanana River (District 6) is divided into three subdistricts, 6-A, 6-B and 6C (Figure 1). Tanana River summer and fall chum salmon are managed as distinct stocks, with 16 August dividing summer and fall seasons. Although some overlap in the migrations does occur, this date has been selected for management purposes based on average historical run timing. With a few exceptions, subsistence and personal-use fisheries in 6-A, 6-B and 6-C are open for two 42-hour periods per week. One exception to this schedule is in the Old Minto area where subsistence fishing is allowed five days a week. Commercial fishery openings occur by emergency order for a maximum of 42-hours per week (24 hours per week in Subdistrict 6-A). The Tanana River commercial guideline harvest range is 2,750 to 20,500 fall chum salmon, but that level of harvest may be exceeded if indications are that escapement goals and subsistence needs will be satisfied. It became evident during 1998 that the fall chum salmon run was much weaker than had been anticipated. Consequently, no commercial fishery was permitted and subsistence fisheries were restricted during the fall season throughout the Alaska portion of the Yukon drainage.

Aside from information provided by this project, management decisions for the Tanana River are partially based on catch-per-unit-effort (CPUE) data from department-contracted "test" fish wheels and fishery performance data. Data obtained from these sources provide an index to qualitatively assess run-strength among years. These data have serious limitations, including an inability to assess absolute run strength. Fish wheels are susceptible to inconsistencies in efficiency, both within and among years. Although attempts are made to fish most test wheels at their same location in each year, conditions at a given location may change annually in relation to water level, current and channel location. The Tanana River is very dynamic, and these factors are known to fluctuate widely. This variability reduces the reliability of test fish wheel data for making in-season management decisions.

Managers also rely on aerial and ground surveys of selected fall chum salmon spawning areas that are considered to be highly productive. For example, ADF&G has established fall chum salmon minimum escapement goals of 33,000 in the Toklat River, a tributary of the Kantishna River, and 11,000 in the Delta River (Buklis 1993). Intensive annual ground surveys are conducted on spawning grounds in each of these rivers to estimate salmon escapement. In addition, a sonar project using Bendix gear was operated in the Toklat River from 1994 to 1996 to develop a better assessment of escapement because it is an important fall chum salmon tributary (Barton 1997).

A sonar project, on the mainsteam of the Yukon River located at river mile 123 near the village of Pilot Station, endeavors to estimate passage of all salmon species in the lower Yukon River. Although in-season assessment of drainage-wide Yukon River fall chum salmon run strength is extremely important, it may not accurately reflect the strength of the Tanana River run component in a given year, due to differences between run strength and run timing between Tanana and non-Tanana stocks. While estimates provided by the main river sonar project may be valuable for the drainage as a whole, determination of the strength of the Tanana River fall chum salmon component is still desirable. A mark-recapture project located at Rampart Rapids on the Yukon River, 58 km upriver of the Tanana-Yukon River confluence, was implemented by the U.S. Fish and Wildlife Service (USFWS) in 1996 to estimate population size of fall chum salmon in the Yukon River above the village of Rampart (Gordon, et al. 1998). Results from this project, in conjunction with estimates from Pilot Station, have the potential to verify Tanana River population estimates.

Previous efforts, limited to one or two years, have been made to estimate population size and identify fall chum salmon spawning areas in the Tanana River. Buklis (1981) estimated population size, including Kantishna River stocks, using mark-recapture methods in 1979 and 1980. Estimates were 676,241 and 383,770, respectively. These estimates were 253% and 125% higher than estimates of harvest plus observed escapement in those years and thought to be positively biased due to mark-recapture assumption violations. In 1990, dual-beam sonar was operated near Manley Hot Springs to estimate passage of salmon in the Tanana River (LaFlamme 1990). Although conditions in the Tanana River may not favor use of sonar at some locations due to changes in water level and heavy debris and silt loads (Buklis 1982), the project near Manley Hot Springs appeared feasible. However, it was not continued in subsequent years because of budget limitations. In 1989, Barton (1992) used radiotelemetry to identify spawning areas in the upper Tanana River. He estimated that Delta River stocks comprised between 11% and 24% of the fall chum salmon in the Tanana River drainage above Fairbanks in that year, and that mainstem spawning was more extensive than was previously thought. An estimate of 121,556 +/- 45,107 (95% C.I.) fall chum salmon above Fairbanks was obtained during that study. However, radiotelemetry is not considered to be economically feasible as an annual monitoring tool.

The Tanana River fall chum salmon mark-recapture project was initiated in 1995 (Cappiello and Bromaghin 1997). Objectives for the 1998 season were to: (1) provide in-season and post-season abundance estimates of fall chum salmon in the upper Tanana River, upstream of the Kantishna River; (2) estimate migration rates; and (3) estimate run timing of selected stocks (e.g., Delta River) in the Tanana River drainage. A successful mark-recapture program provides a management tool capable of assessing absolute numbers of fish, and potentially allows for more accurate in-season estimates of total run size.

In 1995, two tag deployment wheels and two tag recovery wheels were used to sample each river bank (Cappiello and Bromaghin 1997). However, the left bank fall chum salmon catch was approximately 3% of that of the right bank catch. After testing for bank orientation, it was determined that the left bank tag deployment wheel was unnecessary, and it has not been used since. The Bailey closed-population estimator (Seber 1982) was used in 1995 to estimate 268,173 +/- 42,330 (95% C.I.) fall chum salmon in the Tanana River above the Kantishna River. In 1996 the Bailey model was used for making in-season population estimates. However, post-season data did not satisfy model assumptions, as the probability of recapture was not constant through time (Cappiello and Bruden 1997). Therefore, a model which could accommodate temporal stratification (Darroch 1961) was used to produce a post-season estimate of 134,563 +/- 33,212 (95% C.I) fall chum salmon that passed the tag deployment wheel subsequent to 15 August. It was unclear why the probability of recapture varied temporally, although it may have been due to changing efficiencies of the tag deployment and/or recovery wheels with respect to changing water level, current, or abundance of fish in the river (Cappiello and Bruden, 1997). The Darroch model was used again in 1997, resulting in an estimated 71,661 ± 23,277 fall chum salmon upstream of the Kantishna River (Hebert and Bruden 1998).

In 1995 a 6-hour per day tag deployment schedule was used and 4,174 fish were tagged from two fish wheels. In 1996 a 12-hour per day tag deployment schedule was used and 4,016 fish were tagged using only one fish wheel. Cappiello and Bruden (1997) recommended that tag deployment be conducted over the maximum possible number of hours to increase sample size and decrease variability of the estimate. A 12-hour tag deployment schedule was also used in 1997, although chum salmon caught overnight were also tagged to potentially increase the sample size of marked fish used in the abundance estimation. After testing model assumptions, both fish held overnight and those tagged during the 12-hour daily tagging schedule were used in the population abundance estimate in 1998 (Hebert and Bruden 1998).

METHODS

Sampling

Tag Deployment

One fish wheel was used to capture fall chum salmon for tagging in 1998. The wheel, owned and operated by a private contractor, was located on the right bank of the Tanana River approximately 8 km upriver from the mouth of the Kantishna River (Figure 2). Historically, this has been considered a relatively consistent site for fish wheel operation due to stability of the river channel and current. The fish wheel was positioned within 100 meters of the 1995, 1996 and 1997 tag deployment wheel locations and approximately 300 meters downriver from the field camp. It was equipped with two baskets measuring 4 meters and a live-box, measuring 2.4 x 1.2 x 0.6 meters (length, width, depth), constructed of spruce poles and one-half inch plywood, was submerged on the offshore side of the fish wheel. A maximum of three fish leads, ranging from 2 to 5 meters in length, were installed shoreward as needed depending on the distance of the wheel from the river bank. The contractor examined the fish wheel at least once daily for any damage, including tears, rips or holes in the baskets or live-box, as well as to determine overall operating efficiency. Occasional adjustments to the fish wheel were required to maximize operating efficiency, e.g., moving the wheel laterally or raising or lowering the axle to allow baskets to turn as close to the bottom as possible, lengthening or shortening onshore fish leads, and adding or removing basket paddle boards to accommodate changes in river current.

The tag deployment wheel was operated 24 hours per day, unless interrupted by debris problems or wheel relocation, from 17 August until icing conditions prevented the wheel from turning on 5 October. A 12-hour tag deployment schedule was maintained daily from 08:00 to 20:00, with a 24-hour catch-day designated as 08:00 to 08:00 the following day. The sampling crew checked the live-box at approximately 4-hour intervals (07:30, 12:00, 16:00 and 19:30). Sampling was performed by a three-person crew aboard a 22-foot river boat while tied alongside the fish wheel. All chum salmon were individually removed from the live-box with a dipnet and transferred to a sampling table. A 30 cm, hollow core, individually numbered spaghetti tag (Floy Tag and Manufacturing Inc., Seattle, WA)[2] was inserted into the dorsal musculature, posterior to the dorsal fin, with a 16 cm applicator needle. Tags were secured in place with an overhand knot tied close to the body. The right pelvic fin was partially clipped as a secondary mark. Other data recorded were: (1) length, measured from mid-eye to fork of tail (MEFT) and accurate to the nearest 5 cm; (2) sex, as determined by external physical appearance; (3) condition, determined by external physical aberrations subjectively judged as having the potential to affect survival or migration; and (4) color, by grading exterior as light or dark based on ventral, lateral and fin coloration. Fish were also categorized as day fish, caught between 08:00 and 20:00 (tagged with orange tags), or night fish, caught between 20:00 and 08:00 (tagged with yellow tags) and held in the live-box for up to 12 hours. Total handling time per fish was approximately 1 minute. Data were recorded for all chum salmon contained in the live-box during each sampling session. All coho salmon *O. kisutch* and chinook salmon *O. tshawytscha* were enumerated by sex and released, while other species were identified, enumerated and released.

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2 Mention of trade names does not constitute endorsement by ADF&G.

Physical data were collected at the tag deployment wheel during the 07:30 sampling session and included the number of wheel revolutions occurring over a 15-minute interval. Additionally, meteorological data, water temperature and level were recorded once per day at approximately 10:00 hrs at the tagging camp.

Data collected after each sampling session were entered into a computer spreadsheet upon return to camp. A data summary for the previous 24-hour tagging day was reported daily to the ADF&G Fairbanks office via cellular telephone.

Tag Recovery

Two tag recovery fish wheels were located on opposite banks approximately 76 km upriver from the tag deployment fish wheel (Figure 2). Design, size and construction materials of recovery wheels and live-boxes were similar to those of the tag deployment wheel. Recovery wheels were owned and operated by a private contractor hired by ADF&G and the Bering Sea Fishermen's Association (BSFA). The right bank recovery wheel also served as an ADF&G management test fish wheel and was operated during both the summer and fall fishing seasons.

Tag recovery effort began on 16 August to ensure that fish tagged at the tag deployment wheel all had a non-zero probability of recapture at the recovery wheels. Recovery wheels operated 24 hours per day through 6 October, 1998, unless mechanical or debris problems were encountered. Like the tag deployment wheel, recovery wheels were inspected daily and adjusted as necessary. All chum salmon were enumerated by sex with a hand-held counter, and data were recorded in a data book at each recovery wheel site. Chum salmon bearing tags were also enumerated by sex and tag color and identification numbers were recorded. All chum salmon not bearing tags were examined for the secondary mark, a right pelvic fin clip. Additionally, all coho and chinook salmon were enumerated by sex while other species were enumerated daily. The ADF&G office in Fairbanks was contacted daily via cellular telephone to report summary data for the previous 24-hour catch.

A $200 lottery was held to encourage subsistence, personnel use, commercial, and sport fishermen to report tag recoveries. These recoveries provided information concerning migration rate, run timing and spawning location. Tag recoveries were also made by department personnel during surveys of the Delta River spawning grounds.

Data Analysis

Diagnostic Statistical Tests

A series of statistical tests were used to test mark-recapture model assumptions. The significance level for all tests was $\alpha = 0.05$. The tagging schedule was designed to capture and tag fall chum salmon proportional to run size, which would satisfy an assumption of many mark-recapture models. The degree to which this objective was achieved is difficult to assess directly; however, if the objective was achieved, then the proportion of the recovery wheel catch bearing tags, termed marked proportion, should be constant over time. Although a chi-square test of homogeneity could be used to test the hypothesis that the daily marked proportion was constant over time, in previous years and this year as well, many of the observed proportions were quite small, and the distribution of the test statistic may be poorly approximated by the chi-square distribution. For that reason, a randomization test was used and implemented in a FORTRAN program (RANDTEST, Jeff Bromaghin, Alaska Department of Fish and Game, Anchorage). Under the hypothesis that the marked proportion was constant over time, it was estimated as the ratio of the total number of marked fish captured in the recovery wheels to the total number of fish captured in the recovery wheels. The simulation consisted of randomly generating daily numbers of recaptured fish, as a binomial random variable, given the number of fish examined for tags each day and the assumed constant marked proportion. A total of 10,000 such data sets were randomly generated, and a chi-square test statistic was computed for each data set. The p-value of the test was estimated as the proportion of the randomly generated test statistics that exceeded the value of the test statistic computed from the observed data. The same randomization technique and test statistic described above was used to test if the proportion recaptured was constant over time.

A two-sample binomial test (Snedecor and Cochran, 1989) was used to test the hypothesis that the marked proportion was equal in the two recovery wheels, in which case the data from the two recovery wheels could be pooled. Pooling the data from the two recovery wheels is desirable to reduce the variance of the abundance estimate. A non-significant binomial test would also indicate that right bank tagged fish are dispersing to both banks as they move up the Tanana River.

Most mark-recapture models assume that fish have homogeneous probabilities of capture in at least one of the capture events (Seber 1982). Fish wheels are often thought to be selective with respect to size or sex of the fish. In addition, holding fish overnight in the live box could conceivably affect the probability of recapture in the recovery wheels. Whether or not the fish was held in the live box overnight was coded as an indicator variable termed "held." Logistic regression (Agresti 1990) was used to model the probability of recapture as a function of the predictor variables held, sex, and length. All possible interaction terms among the 3 predictive variables were included in the model. Non-significant terms of a similar order, beginning with the 3-way interaction, were removed from the model and a reduced model was fit until the best model possible was obtained. The presence of heterogeneous capture probabilities with respect to sex and size of fish would require the use of a stratified abundance estimate.

Abundance Estimate

The Bailey closed-population model for sampling with replacement (Seber 1982) was used to provide in-season estimates. In-season, the daily number of tags deployed was decreased by 5% to allow for a tagging-induced mortality. True mortality caused by tagging and handling are unknown and inestimable under the circumstances of this study. The mortality rate of 5% has been used in previous years of the study and is similar to the 5.2% of radio-tagged fall chum salmon in the Tanana River that did not proceed upstream (Barton 1992). Final model selection for the abundance estimate depended on post-season analysis of the data and is presented in detail in the results.

Migration Rate

Travel time between the tagging and recovery wheels was calculated to the nearest day for all recaptured fish by subtracting the date of tagging from the date of its first recapture. Analysis of covariance (Neter, Wasserman, and Kutner 1990) was used to test whether the mean travel time was a function of length and two indicator variables, one for sex and one for whether the fish was held in the live box.

Stock Timing

Chum salmon spawning in the Delta River were counted weekly by ground survey and numbers of live and dead salmon were recorded. Tags were retrieved to determine the date that tagged fish passed the tagging wheel site. Nine surveys were conducted on the Delta River from 29 September through 2 December.

RESULTS

Sampling

Tag Deployment

A total of 1,801 tags were deployed from 17 August through 5 October 1998 (Appendix A.1). Of these, 1,146 were day fish and 655 were night fish. Of the entire chum salmon catch, 13 fish were not tagged. Nine of these chum salmon escaped during processing and 4 were mortalities. In 1995, 1996 and 1997, totals of 4,083, 4,016 and 1,254 chum salmon were tagged, respectively, during approximately the same time period. On the last day of tag deployment, one tag was recovered from a mark-recapture project conducted by the USFWS on the mainstem of the Yukon River near Rampart Rapids.

Catch per unit effort (CPUE) was low throughout most of the field season (Figure 4). As of 15 September, only 431 tagged chum salmon had been released, out of a total catch of 439, compared with 2,517, 2,072, and 933 as of the same date in 1995, 1996, and 1997 respectively. The peak catch at the tagging wheel occurred on 30 September and catches remained relatively strong towards the end of the study indicating late run timing for fall chum salmon in 1998. Consequently, the tagging period was extended to 6 October.

Due to low catch rates and changes in river current at the tagging wheel site, the fish wheel was relocated on four occasions. However, wheel relocations were in the general vicinity of the original location, along the same bluff on the right bank of the river. The final movement of the tagging wheel occurred on 23 September and coincided with an increase in CPUE.

Tag Recovery

A total of 3,244 chum salmon were examined for marks in both recovery wheels: 1,282 in the right-bank and 1,962 in the left-bank wheel (Appendix B.1, B.2). There were 85 recaptures in both recovery wheels, which included both day and night-tagged fish (Figure 4). The right-bank wheel recaptured 33 fish while the left-bank wheel recaptured 52 fish. Of the 33 fish recaptured in the right-bank wheel, two had a secondary mark only. One had been previously captured in the right-bank recovery wheel. All of the 52 recaptures in the left-bank recovery wheel bore their primary mark, and three had been recaptured previously; two in the right-bank and one in the left-bank recovery wheel. Five tags were recovered from the USFWS Rampart Rapids mark-recapture project.

A total of 168 tags were returned by various sources other than project recovery wheels (Table 1). The greatest number of tags (107) were recovered from fish wheels located near Nenana. In addition, 58 tags were recovered in spawning areas of the Delta River. One tag was recovered from the Toklat River coded wire tag camp, and two tags were found in Bluff Cabin Slough by USFWS personnel.

Data Analysis

Migration Rate

A total of 85 fall chum salmon were recaptured in the left and right bank recovery wheels between 16 August and 6 October. The predictive variables sex, held and length were used in an analysis of covariance model (Neter, Wasserman, and Kutner 1990), with travel time (measured in days) as the response variable. The mean travel time for night-tagged fall chum salmon was similar ($\bar{x}$ = 2.47, n = 31) to the mean for day-tagged fall chum salmon ($\bar{x}$ = 2.64, n = 50). Figure 5 depicts the empirical distributions of travel time for day-and night-tagged fall chum salmon. There were no discernable trends over time in the number of days required for fall chum salmon to travel between the tagging and recovery wheels (Figure 6).

Migration rate was calculated by dividing the distance between the tag deployment wheel and recovery wheels (76 km) by travel time. The average migration rate between the tag deployment and recovery wheels was 30 km/d for day and night-tagged fish. The average migration rate for day and night fish in 1997 was 21 km/day. The average migration rate for day-fish in 1995 and 1996 was 26 km/d and 31 km/d, respectively.

Diagnostic Statistical Tests

Under the hypothesis that the marked proportion (proportion of recovery wheel catch bearing tags) was constant over time, it was estimated as the ratio of the total number of marked fish to the total number captured, 85/3,244 = 0.026. Because many of the observed marked proportions (Figure 7) were at or close to zero, simulation techniques described previously were used to estimate the distribution of the test statistic. A chi-square test statistic was computed using the observed data and the estimated marked proportion, resulting in a test statistic of 132.55 (48 df). The proportion of the randomly generated test statistics that exceeded the value of the test statistic computed with the observed data was 0.000, which is an estimate of the p-value associated with the test statistic. Given the highly significant result of this test, the marked proportion could not be assumed constant through time.

Under the hypothesis that the proportion recaptured (proportion of tagged fish released at the tagging wheel that were subsequently recaptured) was constant over time, it was estimated as the total number of recaptures to the total number of marked fish released, 76/1,565 = 0.049. Multiple recaptures and fish marked and released after 2 October were excluded from the data set for this test. Again, because many of the observed proportions are at or close to zero (Figure 8), the same simulation technique was used to estimate the distribution of the test statistic. A chi-square test statistic was computed using the observed data and the estimated proportion recaptured, resulting in a test statistic of 70.49 (46 df, Table 2). The proportion of the randomly generated test statistics that exceeded the value of the test statistic computed with the observed data was 0.035, which is an estimate of the p-value associated with the test statistic. Although the test was significant, 27.79% of the test statistic could be attributed to a single day, 17 August. On 17 August one fish was released with a tag and was subsequently recaptured, which led to a proportion recaptured of 1.0 for that particular day. With the one fish on 17 August eliminated from the data set, the chi-square test statistic was 51.50 (45 df), and the estimated p-value from the randomizations was 0.242. Given the non-significant estimated p-value, with the outlier removed from the data set, the probability of recapture at the recovery wheels was assumed constant through time.

A two-sample binomial test was used to test the hypothesis that the marked proportions in the two recovery wheels were equal. The marked proportions in the left (52/1,962 = 0.0265) and right bank (33/1,282 = 0.0257) were not significantly different ($z = 0.406$, $P \approx 0.685$). Consequently, the data from the two recovery wheels were pooled for the post-season abundance estimate.

A total of 76 fall chum salmon were subsequently recaptured from the 1,565 tagged and released between 17 August and 2 October. Three predictor variables were included in a logistic regression model (Agresti 1990): sex, held and length. The data were sufficient to test only one interaction term among the three predictor variables. A sex-by-length interaction term was also included in the model as it was significant in a previous year's analysis (Cappiello and Bruden 1997). A likelihood ratio test (Agresti 1990) revealed that none of the variables or the interaction term influenced the probability of recapture ($P \approx 0.932$). This test suggested that capture probabilities were homogeneous with respect to sex, length, and the variable "held."

Abundance Estimate

The Bailey closed-population model for sampling with replacement (Seber 1982) was used to provide in-season abundance estimates (Table 3). The daily number of tags released increased substantially during the last 10 days of the study. On days when a large number of tags were released (relative to the total number of tags released to date), the abundance estimate increased substantially as would be expected. When a large number of tags were released over a several-day interval, the abundance estimate increased substantially and then decreased as the recaptures from the interval began to be incorporated into the abundance estimate. This indicates an increased efficiency in the tagging wheel.

Failure to meet the assumption that the marked proportion was constant through time suggested the need for a temporally stratified estimator. We used the Darroch estimator for stratified populations (Darroch 1961) for the final post-season abundance estimate. The Darroch estimator conditions on the number of tags released in each stratum, so the assumption of tagging in proportion to abundance of the run is not needed.

The notation used here follows Darroch (1961). Subscript i refers to the tagging stratum and subscript j refers to the recovery stratum. Let a_i = the number of tagged fish released in stratum i, let c_{ij} = the number of tagged fish released in stratum i that are recaptured in recovery stratum j and let b_j = the number of untagged fish captured in recovery stratum j. The stratified estimate of the number of unmarked fish in the population ($\hat{n}$) was

$$\hat{n} = b'C^{-1}a$$

where b is a vector with elements b_j, C is a matrix with elements c_{ij}, and a is a vector with elements a_i.

Tagging began on 17 August and we used data from the recovery wheels beginning on 18 August. Based on the distribution of travel times for day-tagged fish (Table 4), we assumed that some of the unmarked fish captured in the recovery wheels between 18 and 25 August passed the tagging wheel before it was operational. The capture of unmarked fish in the recovery wheels that did not pass the tagging wheel while it was operational is a violation of the closure assumption and would positively bias the abundance estimator. For that reason, a method to subset the data was adopted.

We used the distribution of travel times for day-tagged fish to remove a proportion of the unmarked fish between 18 and 23 August. For each day, the number of unmarked fish was multiplied by the appropriate cumulative frequency, which resulted in a final vector of the daily number of unmarked fish captured in the recovery wheels (Table 5). We assumed that the distribution of travel times of day-tagged fish was an accurate representation of the distribution of travel times of unmarked fish. This assumption is not testable, and it could be that day-tagged fish have longer travel time than unmarked fish because of a need to "recover" from the tagging process. However, the travel times of day-tagged fish are the only information available to estimate the proportion of unmarked fish early on in the recovery wheel catches that passed the tagging wheel location while it was operational.

Tagging ended on 5 October and recovery efforts ended on 6 October. Similar to the unmarked fish at the beginning of the study, a proportion of the fish tagged between 27 September and 5 October did not pass the recovery wheels while they were operational. Using the distribution of travel times for day- and night-tagged fish, the corresponding number of day- and night-tagged fish released between 27 September and 5 October was reduced (Table 5). The data used in the final Darroch estimate are shown in Table 6.

The final estimate of the number of unmarked fish ($\hat{n}$) was 60,814 which, when added to the mortality-adjusted number of marked fish, 1,570, resulted in a final abundance estimate of 62,384 (SE = 12,076). The 95% confidence interval was (38,715; 86,053) and the coefficient of variation was approximately 0.19. Population estimates and standard errors of individual strata are presented in Table 7. The 1998 subsistence and personal use harvest estimate in the Tanana River for subdistricts 6-B and 6-C was approximately 9,575 fall chum salmon (Borba and Hamner 1999). There were no commercial chum salmon openings in the Tanana River during 1998. Removal of reported subsistence harvest from the chum salmon abundance estimate leaves an estimated escapement in the upper Tanana River of approximately 52,809 fall chum salmon. For comparison, estimates of spawning escapement to the upper Tanana River in 1995, 1996, and 1997 were 183,267, 83,447, and 62,448 fall chum salmon, respectively.

Stock Timing

A total of 55 tags were recovered during surveys of spawning grounds in the Delta River. These tags were recovered during 9 weekly surveys of the Delta River between 29 September and 2 December, 1998. The median tag deployment date was 27 September, and tagging dates ranged from 5 September through 5 October (Figure 10). The median tag deployment date for tags recovered in the Delta River in 1995, 1996, and 1997 was 14 September, and the absolute number of tags recovered was 39, 183, and 26 respectively. Two tags were recovered by USFWS personnel from Bluff Cabin Slough, a side channel of the Tanana River located several kilometers upstream of the mouth of the Delta River.

DISCUSSION

The water level of the Tanana River in 1998, as measured by a U.S. Geological Survey gauge near Nenana, remained below the normal 1995 -1997 average. Consequently, the recovery wheels were not relocated during the study period, and there were minimal problems with the wheels' operation (Figure 3).

The relatively low numbers of tags being deployed was a concern in-season. The tag deployment wheel was relocated four times in September in attempts to increase the number of tags being deployed. Catches increased markedly after the final move on 23 September. Whether the increase in catch was caused by increased efficiency of the wheel or a coincidental increase in fish abundance is not known with certainty. However, recovery wheel catches did not increase to nearly the same degree and the marked proportion increased, which suggests that the efficiency of the tag-deployment wheel likely increased to some extent. Because of these changes in the marked proportion through time, a temporally stratified Darroch model was used post-season to estimate fall chum salmon abundance.

The 1998 estimated escapement of 52,740 fall chum salmon was 46% of the 1995-1997 average of 109,721 and the lowest since the project's inception. Other run assessment tools indicated the run timing was approximately 10 ten days later than average and below average in magnitude. The 1998 Pilot Station sonar passage estimate in the lower Yukon River was only 397,000 fall chum salmon (Bergstrom et al. 1999), wich was well below average. Similarly, the ADF&G test fish wheel located on the left bank of the Yukon River near the village of Tanana caught approximately 41% of its 1994-1997 average annual fall chum salmon catch. Moreover, spawning ground surveys in the

Toklat River revealed an escapement of 15,605 chum salmon in 1998 which is 47% of the minimum escapement goal of 33,000. Similarly, the spawning escapement in the Delta River was 7,804 chum salmon, which is 71% of the minimum escapement goal of 11,000 (Bergstrom, et al, 1999).

The probability of recapture was not significantly different for day-and night-tagged fish, nor was it in 1997. For that reason, both day-and night-tagged fish were used in the abundance estimates. We will continue to monitor the effect of length of holding time in the live-box on the probability of recapture because it has only been examined in years of low abundance and live-box densities.

The season average rate of 30 km/d was similar to chum salmon migration rates observed in 1996 (31 km), and 1995 (26 km/d) and documented by other studies (Milligan et al. 1984; Buklis and Barton 1984). Despite late run timing in 1998, the average travel rates appear to be somewhat normal compared with other years.

The abundance estimate in this study represents the number of fall chum salmon that passed the tagging site between 16 August and 6 October. Thus, our estimate could be considered conservative from that standpoint. At the end of the study, wheel catches remained relatively high, suggesting that a potentially substantial number of fall chum salmon may have migrated up the Tanana River after project operations ceased. Conversely, the abundance estimate may have included fish that migrated up the Kantishna or Tolovana Rivers, or those that migrated elsewhere downstream of the tagging site. However, closure violations that occur with equal rates among marked and unmarked fish should not bias the abundance estimate.

Another assumption of all mark-recapture models is that there is no tag loss. In this study, the right pelvic fin was clipped as a secondary mark to examine this assumption. The rate of tag loss was low, as it has been since the initiation of this project. Only two recaptures out of 85 were missing their primary mark. However, the recovery of even a small number of fall chum salmon without their primary mark warrants the continued use of a secondary mark, particularly for years of low abundance.

RECOMMENDATIONS

Model development efforts should continue in order to provide more refined in-season and post-season tools for population estimation. Other data analysis tools should be explored and developed to test as many assumptions as possible.

The current tag-deployment site has been used since project inception. Fewer tags were deployed in the last two years than desired, reducing the precision and causing staff to question the viability of the project in years of low abundance. There has also been some speculation that the suitability of the tagging site may have deteriorated as has been suggested by the fish wheel contractor. Concern over low sample sizes required that the wheel be moved several times over the course of the season. Consideration should be given to finding a more efficient tagging wheel location, as well as use of an additional tagging wheel in years when the abundance is expected to be low.

We also recommend that day- and night-fish continue to be tagged to increase sample size, when possible. Had we not done so this year, the precision of the abundance estimate would have been lower. Plans to tag day- and night-fish may require in-season modification. During years of high abundance, it may be logistically impossible for the crew to tag all night-fish, and their inseason use would violate the assumption of tagging in proportion to abundance. Based on results from 1998 and 1997, tagging chum salmon that are held in a live-box overnight for up to 12 hours does not have a detectable effect on their probability of recapture when the number of fish in the live-box is low. Pooling data from day- and night-fish can substantially increase the number of marked fish, which significantly reduces the variance of the abundance estimate. Day- and night-fish should be pooled only after tests are performed to verify that no differences exist as a result of long-term (12-hour) holding in the live-box.

At the end of the season, ADF&G staff began to investigate the feasibility of relocating the project fish wheels in order to obtain abundance estimates for both the Kantishna River fall chum salmon component and the upper Tanana River component. A change in project configuration was considered because of the low sample size at the present tagging wheel location and because of the importance of the Toklat River fall chum salmon stock. An expanded mark-recapture project would involve moving the tagging wheel to a location below the confluence of the Kantishna River, as well as deploying a second tagging wheel on the opposite bank. One recovery wheel would remain at the present location, and two fish wheels currently employed on the Toklat River would be used as recovery wheels. Obtaining separate Kantishna and non-Kantishna abundance estimates will require that the two stocks be tagged differentially. ADF&G staff will continue to evaluate the feasibility of developing an expanded mark-recapture project in the Tanana River drainage during the spring of 1999.

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Table 1. Number of tags returned by location from fall chum salmon tagged in the Tanana River, 1998.

Recapture Location	Number of Tags
Delta River	58
Tanana River, Nenana	107
Tanana River, Bluff Cabin Slough	2
Toklat River	1
Total	168

Table 2. Chi-square test results on daily probability of recapture of fall chum salmon and number tagged subsequently recovered in the Tanana River, 1998.

Date	Observed Data			Expected Data			Chi-Square Components			
of Release	Recaptured	Not Recaptured	Tags Released	Recaptured	Not Recaptured	Total	Recaptured	Not Recaptured	Total	Percent
8/17	1	0	1	0.05	0.95	1	18.64	0.95	19.59	27.79
8/18	0	3	3	0.15	2.85	3	0.15	0.01	0.15	0.22
8/19	1	17	18	0.87	17.13	18	0.02	0.00	0.02	0.03
8/20	2	14	16	0.78	15.22	16	1.93	0.10	2.02	2.87
8/21	3	28	31	1.51	29.49	31	1.48	0.08	1.56	2.21
8/22	1	14	15	0.73	14.27	15	0.10	0.01	0.11	0.15
8/23	2	11	13	0.63	12.37	13	2.97	0.15	3.12	4.42
8/24	0	15	15	0.73	14.27	15	0.73	0.04	0.77	1.09
8/25	0	12	12	0.58	11.42	12	0.58	0.03	0.61	0.87
8/26	0	7	7	0.34	6.66	7	0.34	0.02	0.36	0.51
8/27	0	6	6	0.29	5.71	6	0.29	0.01	0.31	0.43
8/28	1	2	3	0.15	2.85	3	5.01	0.26	5.27	7.47
8/29	1	8	9	0.44	8.56	9	0.73	0.04	0.76	1.08
8/30	1	11	12	0.58	11.42	12	0.30	0.02	0.31	0.45
8/31	0	32	32	1.55	30.45	32	1.55	0.08	1.63	2.32
9/1	1	13	14	0.68	13.32	14	0.15	0.01	0.16	0.22
9/2	2	13	15	0.73	14.27	15	2.22	0.11	2.33	3.31
9/3	1	11	12	0.58	11.42	12	0.30	0.02	0.31	0.45
9/4	0	16	16	0.78	15.22	16	0.78	0.04	0.82	1.16
9/5	2	13	15	0.73	14.27	15	2.22	0.11	2.33	3.31
9/6	2	9	11	0.53	10.47	11	4.02	0.21	4.23	6.00
9/7	1	5	6	0.29	5.71	6	1.72	0.09	1.81	2.57
9/8	0	8	8	0.39	7.61	8	0.39	0.02	0.41	0.58
9/9	0	10	10	0.49	9.51	10	0.49	0.02	0.51	0.72
9/10	1	23	24	1.17	22.83	24	0.02	0.00	0.02	0.04
9/11	1	29	30	1.46	28.54	30	0.14	0.01	0.15	0.21
9/12	0	39	39	1.89	37.11	39	1.89	0.10	1.99	2.82
9/13	1	12	13	0.63	12.37	13	0.22	0.01	0.23	0.32
9/14	0	16	16	0.78	15.22	16	0.78	0.04	0.82	1.16
9/15	0	9	9	0.44	8.56	9	0.44	0.02	0.46	0.65
9/16	0	11	11	0.53	10.47	11	0.53	0.03	0.56	0.80
9/17	1	16	17	0.83	16.17	17	0.04	0.00	0.04	0.05
9/18	1	19	20	0.97	19.03	20	0.00	0.00	0.00	0.00
9/19	1	11	12	0.58	11.42	12	0.30	0.02	0.31	0.45
9/20	0	9	9	0.44	8.56	9	0.44	0.02	0.46	0.65
9/21	0	10	10	0.49	9.51	10	0.49	0.02	0.51	0.72
9/22	0	18	18	0.87	17.13	18	0.87	0.04	0.92	1.30
9/23	1	22	23	1.12	21.88	23	0.01	0.00	0.01	0.02
9/24	4	66	70	3.40	66.60	70	0.11	0.01	0.11	0.16
9/25	6	58	64	3.11	60.89	64	2.69	0.14	2.83	4.01
9/26	1	66	67	3.25	63.75	67	1.56	0.08	1.64	2.33
9/27	3	98	101	4.90	96.10	101	0.74	0.04	0.78	1.10
9/28	2	102	104	5.05	98.95	104	1.84	0.09	1.94	2.75
9/29	5	122	127	6.17	120.83	127	0.22	0.01	0.23	0.33
9/30	15	162	177	8.60	168.40	177	4.77	0.24	5.02	7.12
10/1	7	136	143	6.94	136.06	143	0.00	0.00	0.00	0.00
10/2	4	157	161	7.82	153.18	161	1.86	0.10	1.96	2.78
Totals	76	1489	1565	76	1489	1565	67.07	3.42	70.49	100.00

Table 3. Daily cumulative catch statistics and Bailey abundance estimates of fall chum salmon in the Tanana River, 1998. a

Date	Adjusted (Releases)	Examined For Tags	Recaptures	Abundance	95% Confidence Bounds Lower	95% Confidence Bounds Upper	Standard Error	CV
8/16	0							
8/17	1							
8/18	4	61	0	248	0	589	174	0.70
8/19	21	112	0	2,373	0	5,647	1,671	0.70
8/20	36	156	1	2,826	0	6,003	1,621	0.57
8/21	66	196	1	6,501	0	13,820	3,734	0.57
8/22	80	251	3	5,040	657	9,423	2,236	0.44
8/23	92	304	3	7,015	907	13,123	3,117	0.44
8/24	106	360	7	4,783	1,693	7,873	1,577	0.33
8/25	118	431	9	5,098	2,121	8,075	1,519	0.30
8/26	124	500	10	5,648	2,488	8,808	1,612	0.29
8/27	130	563	12	5,640	2,720	8,560	1,490	0.26
8/28	133	619	12	6,343	3,055	9,631	1,677	0.26
8/29	142	660	12	7,220	3,475	10,965	1,911	0.26
8/30	153	709	12	8,356	4,019	12,693	2,213	0.26
8/31	183	764	13	10,000	4,986	15,014	2,558	0.26
9/1	197	799	15	9,850	5,215	14,485	2,365	0.24
9/2	211	831	15	10,972	5,807	16,137	2,635	0.24
9/3	222	869	16	11,361	6,164	16,558	2,652	0.23
9/4	238	902	17	11,940	6,625	17,255	2,712	0.23
9/5	252	943	18	12,520	7,088	17,952	2,771	0.22
9/6	262	984	18	13,583	7,688	19,478	3,008	0.22
9/7	268	1,022	20	13,055	7,656	18,454	2,755	0.21
9/8	276	1,055	21	13,248	7,890	18,606	2,733	0.21
9/9	285	1,110	23	13,193	8,077	18,309	2,610	0.20
9/10	308	1,153	24	14,217	8,812	19,622	2,758	0.19
9/11	336	1,197	25	15,482	9,706	21,258	2,947	0.19
9/12	373	1,226	26	16,951	10,742	23,160	3,168	0.19
9/13	386	1,303	27	17,977	11,505	24,449	3,302	0.18
9/14	401	1,368	27	19,606	12,543	26,669	3,603	0.18
9/15	409	1,457	29	19,877	12,952	26,802	3,533	0.18
9/16	420	1,535	29	21,504	14,008	29,000	3,824	0.18
9/17	436	1,599	29	23,253	15,144	31,362	4,137	0.18
9/18	455	1,692	29	25,677	16,718	34,636	4,571	0.18
9/19	466	1,807	30	27,178	17,842	36,514	4,763	0.18
9/20	475	1,935	31	28,738	19,014	38,462	4,961	0.17
9/21	485	2,001	32	29,423	19,615	39,231	5,004	0.17
9/22	502	2,072	32	31,535	21,020	42,050	5,365	0.17
9/23	523	2,133	32	33,821	22,541	45,101	5,755	0.17
9/24	590	2,185	32	39,083	26,045	52,121	6,652	0.17
9/25	651	2,245	33	43,004	28,865	57,143	7,214	0.17
9/26	714	2,325	35	46,132	31,383	60,881	7,525	0.16
9/27	810	2,448	40	48,383	33,873	62,893	7,403	0.15
9/28	909	2,542	42	53,758	38,008	69,508	8,035	0.15
9/29	1,030	2,629	47	56,435	40,778	72,092	7,988	0.14
9/30	1,198	2,699	47	67,388	48,688	86,088	9,541	0.14
10/1	1,334	2,787	52	70,173	51,635	88,711	9,458	0.13
10/2	1,487	2,849	54	77,054	57,068	97,040	10,197	0.13
10/3	1,555	2,927	62	72,270	54,755	89,785	8,936	0.12
10/4	1,662	2,999	74	66,480	51,721	81,239	7,530	0.11
10/5	1,711	3,062	81	63,912	50,347	77,477	6,921	0.11
10/6	1,711	3,116	85	62,014	49,164	74,864	6,556	0.11

a The number of tags deployed was adjusted for a 5% mortality.

Table 4. Counts and cumulative frequencies of travel time between the tag deployment and recovery wheels on the Tanana River used in the data reduction for the Darroch estimator, 1998.

Travel Time (days)	Day Tag Count	Day Tag Cumulative Frequency	Night Tag Count	Night Tag Cumulative Frequency	Combined Count	Combined Cumulative Frequency
1	0	0.000	0	0.000	0	0.000
2	23	0.489	4	0.138	27	0.355
3	29	0.894	12	0.552	31	0.763
4	4	0.979	10	0.897	14	0.947
5	1	1.000	2	0.966	3	0.987
6	0	1.000	0	0.966	0	0.987
7	0	1.000	0	0.966	0	0.987
8	0	1.000	0	0.966	0	0.987
9	0	1.000	1	1.000	1	1.000

Table 5 Observed and adjusted number of releases at the tag deployment wheel and observed and adjusted number of unmarked catches at the recovery wheels used in the Darroch model to estimate abundance of fall chum salmon in the Tanana River, 1998.

		Releases at Tagging Wheel						Unmarked Catches at Both Recovery Wheels		
Date	Release Stratum	Day Tags Released	Estimated Proportion Passing Recovery Wheels	Night Tags Released	Estimated Proportion Passing Recovery Wheels	Adjusted Tags Released	Recovery Stratum	Unmarked Catch	Estimated Proportion Passing Tagging Wheel	Adjusted Unmarked Catch
8/17	1	0	0.95	1	0.95	1				
8/18	1	1	0.95	2	0.95	3	1	61	0.35	22
8/19	1	10	0.95	8	0.95	17	1	51	0.77	39
8/20	1	8	0.95	8	0.95	15	1	44	0.95	42
8/21	1	15	0.95	16	0.95	29	1	40	0.99	39
8/22	1	8	0.95	7	0.95	14	1	54	0.99	53
8/23	1	10	0.95	3	0.95	12	1	53	0.99	52
8/24	1	7	0.95	8	0.95	14	1	52	0.99	51
8/25	1	7	0.95	5	0.95	11	1	69	0.99	68
8/26	1	4	0.95	3	0.95	7	1	68	1.00	68
8/27	1	2	0.95	4	0.95	6	1	61	1.00	61
8/28	1	0	0.95	3	0.95	3	1	56	1.00	56
8/29	1	2	0.95	7	0.95	9	1	41	1.00	41
8/30	1	7	0.95	5	0.95	11	1	49	1.00	49
8/31	1	16	0.95	16	0.95	30	1	54	1.00	54
9/1	1	11	0.95	3	0.95	13	1	33	1.00	33
9/2	1	7	0.95	8	0.95	14	1	32	1.00	32
9/3	1	7	0.95	5	0.95	11	1	37	1.00	37
9/4	1	9	0.95	7	0.95	15	1	32	1.00	32
9/5	1	9	0.95	6	0.95	14	1	40	1.00	40
9/6	1	7	0.95	4	0.95	10	1	41	1.00	41
9/7	1	1	0.95	5	0.95	6	1	36	1.00	36
9/8	2	5	0.95	3	0.95	8	1	32	1.00	32
9/9	2	1	0.95	9	0.95	10	2	53	1.00	53
9/10	2	15	0.95	9	0.95	23	2	42	1.00	42
9/11	2	18	0.95	12	0.95	29	2	43	1.00	43
9/12	2	21	0.95	18	0.95	37	2	28	1.00	28
9/13	2	5	0.95	8	0.95	12	2	76	1.00	76
9/14	2	5	0.95	11	0.95	15	2	65	1.00	65
9/15	2	6	0.95	3	0.95	9	2	87	1.00	87
9/16	2	5	0.95	6	0.95	10	2	78	1.00	78
9/17	2	13	0.95	4	0.95	16	2	64	1.00	64
9/18	2	13	0.95	7	0.95	19	2	93	1.00	93
9/19	2	9	0.95	3	0.95	11	2	114	1.00	114
9/20	2	6	0.95	3	0.95	9	2	127	1.00	127
9/21	2	5	0.95	5	0.95	10	2	65	1.00	65
9/22	3	12	0.95	6	0.95	17	2	71	1.00	71
9/23	3	9	0.95	14	0.95	22	3	61	1.00	61
9/24	3	54	0.95	16	0.95	67	3	52	1.00	52
9/25	3	42	0.95	22	0.95	61	3	59	1.00	59
9/26	3	32	0.95	35	0.95	64	3	78	1.00	78
9/27	3	68	0.95	33	0.92	95	3	118	1.00	118
9/28	3	67	0.95	37	0.92	98	3	92	1.00	92
9/29	3	92	0.95	35	0.92	119	3	82	1.00	82
9/30	3	111	0.95	66	0.92	166	3	70	1.00	70
10/1	3	100	0.95	43	0.92	134	3	83	1.00	83
10/2	3	122	0.93	39	0.85	145	3	60	1.00	60
10/3	3	58	0.85	14	0.52	53	3	70	1.00	70
10/4	3	73	0.46	39	0.13	38	3	60	1.00	60
10/5	3	31	0.00	21	0.00	1	3	56	1.00	56
10/6		0		0		0	3	50	1.00	50

Table 6. The number of tagged fish recaptured by tagging and recovery stratum, the number of tagged fish released in each tagging stratum, and the number of unmarked fish caught in the recovery wheels by recovery stratum on the Tanana River, 1998.

Tagging	Recovery Stratum			Total	Tags
Stratum	08/18-09/08	09/09-09/22	09/23-10/06	Recovered	Released
08/17-09/07	21	5	0	26	268
09/08-09/21	0	6	0	6	217
09/22-10/05	0	0	53	53	1,085
Total	21	11	53	85	1,570
Unmarked Catch	998	1,006	991	2,995	

Table 7. Stratum abundance and probability of capture estimates from the Darroch model, Tanana River, 1998.

Tagging Strata	Abundance Estimate	Standard Error	Probability of Capture	Standard Error
08/17-09/07	13,004	2,750	0.0210	0.005
09/08-09/21	28,007	12,067	0.0078	0.003
09/22-10/05	21,372	2,711	0.0535	0.007

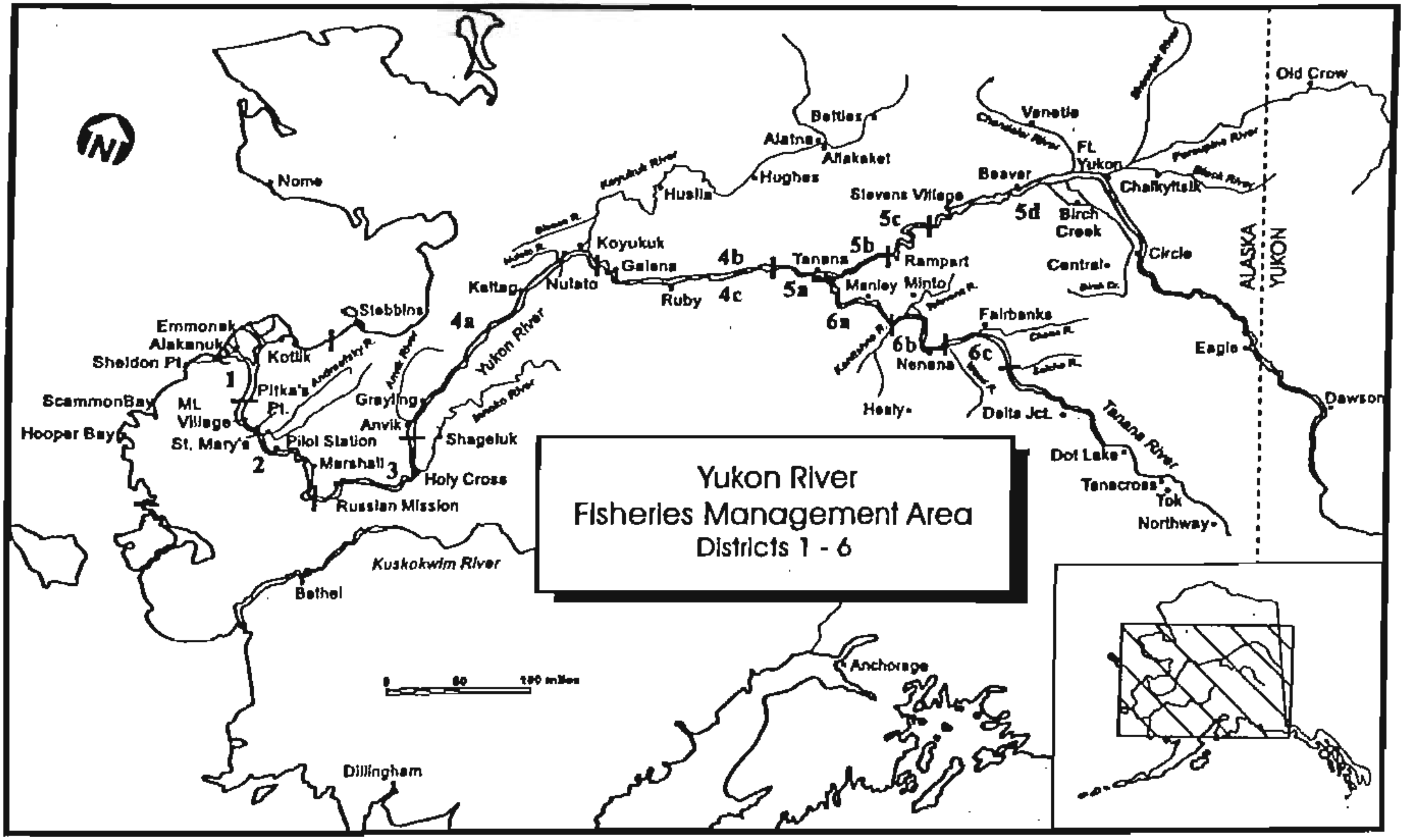

Figure 1. Fisheries management districts and subdistricts in the Yukon and Tanana River drainages.

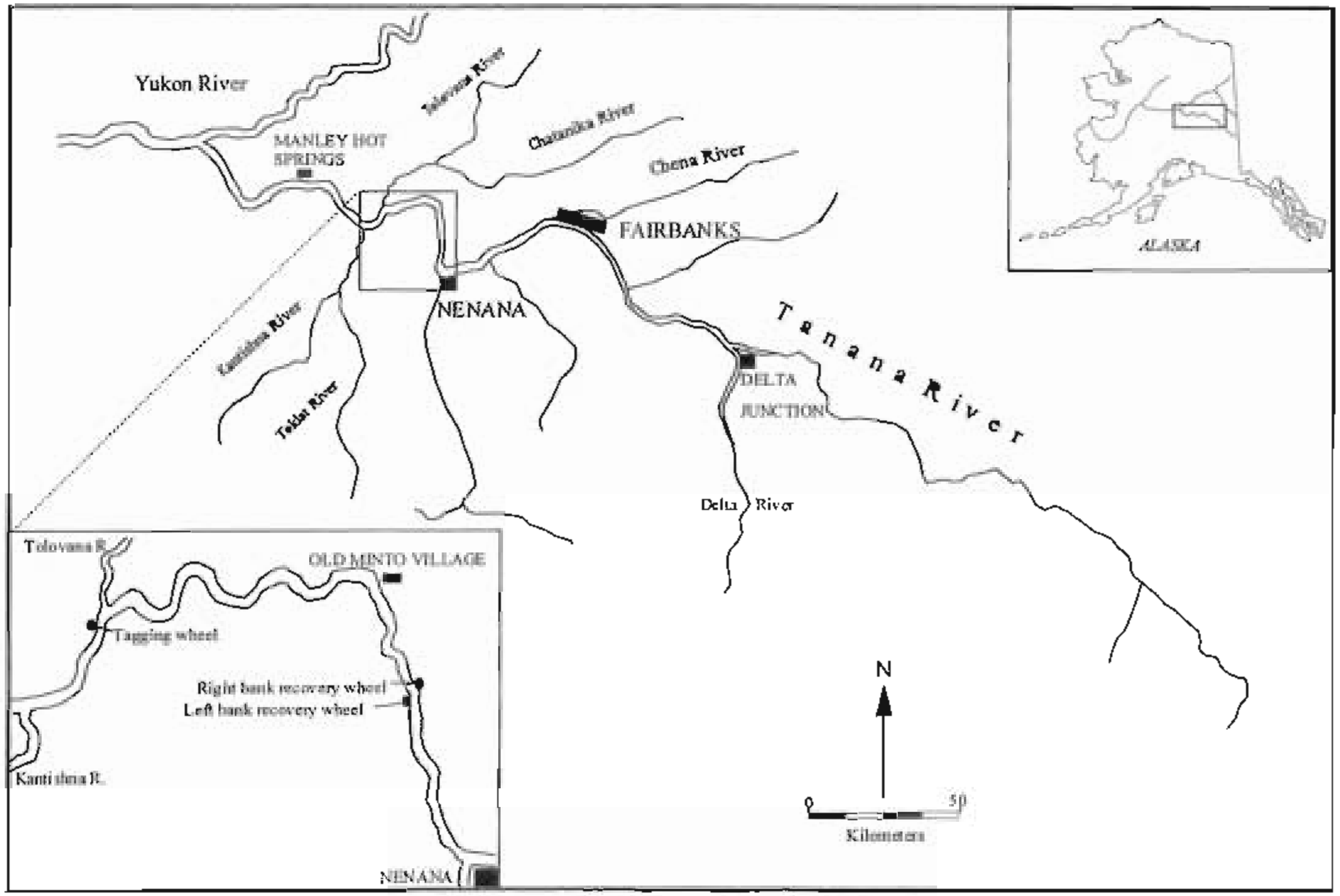

Figure 2. Location of the tag deployment fish wheel and the tag recovery fish wheels used for the Tanana River fall chum tagging project, 1998.

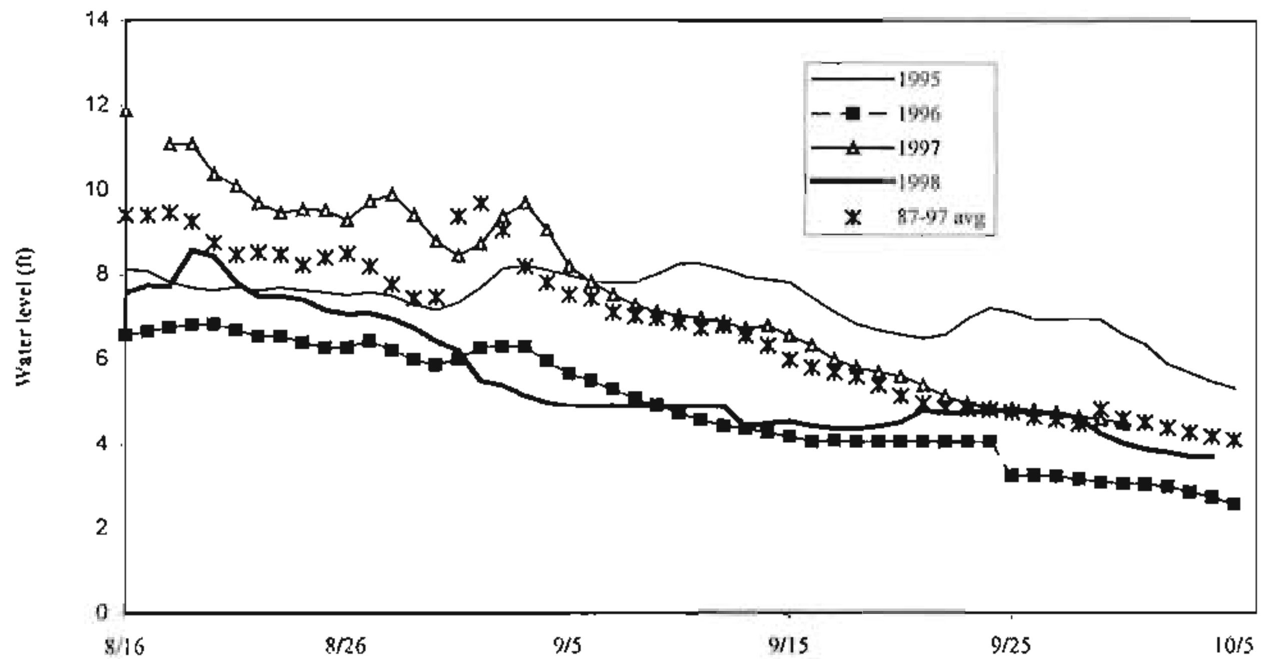

Figure 3. Daily water levels on the Tanana River, 1995 - 1998, as measured by a U.S. Geological Survey gauge located near Nenana.

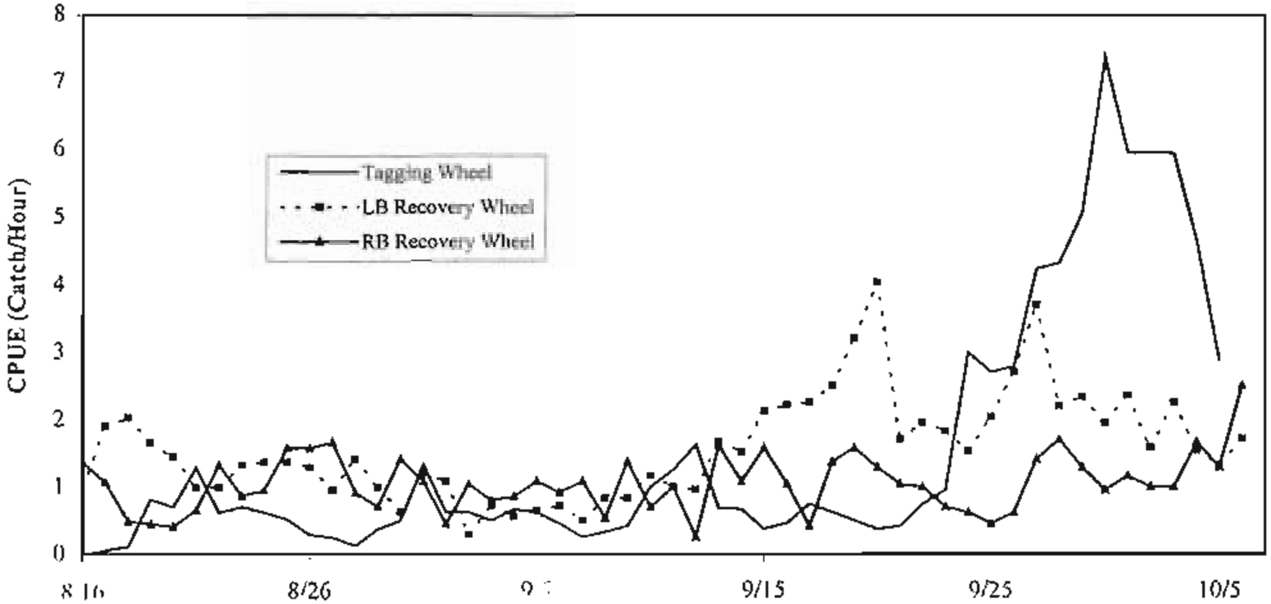

Figure 4. Daily catch-per-hour-effort (CPUE) of fall chum salmon at the tag deployment and recovery fish wheels, Tanana River, 1998.

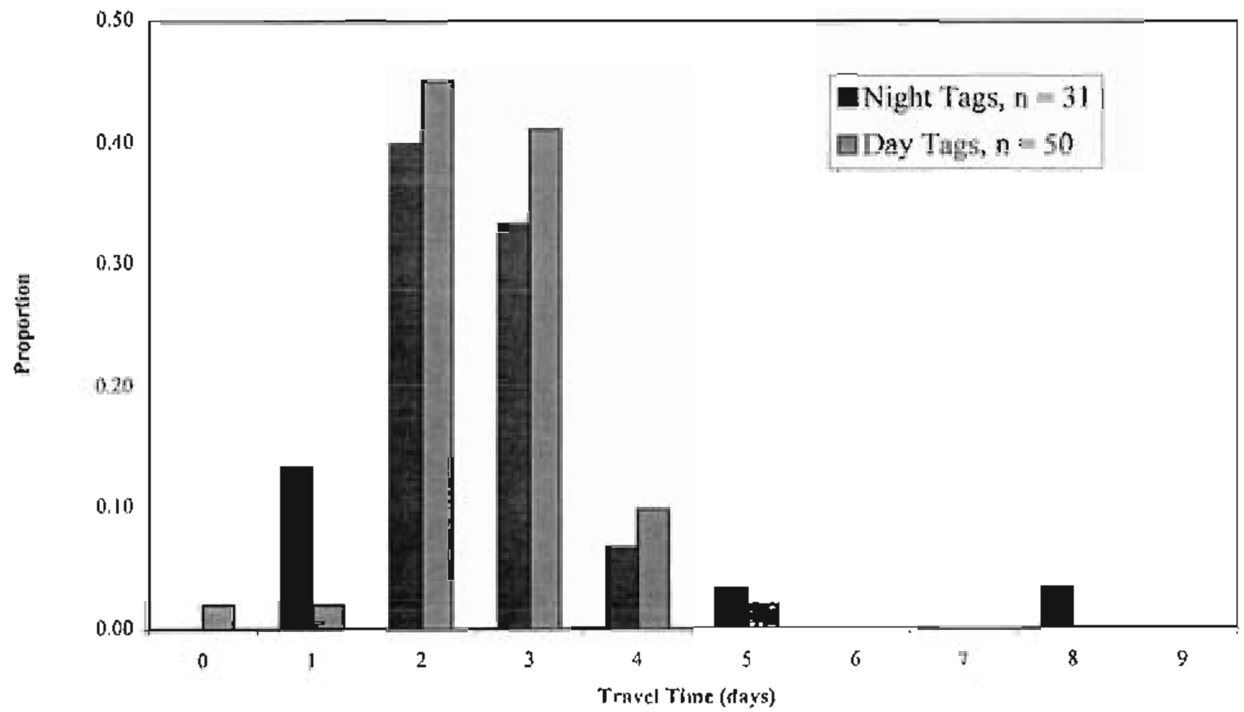

Figure 5. Travel time in days between the tagging wheel and recovery wheels for day and night fish that were recaptured at the recovery wheels, Tanana River, 1998.

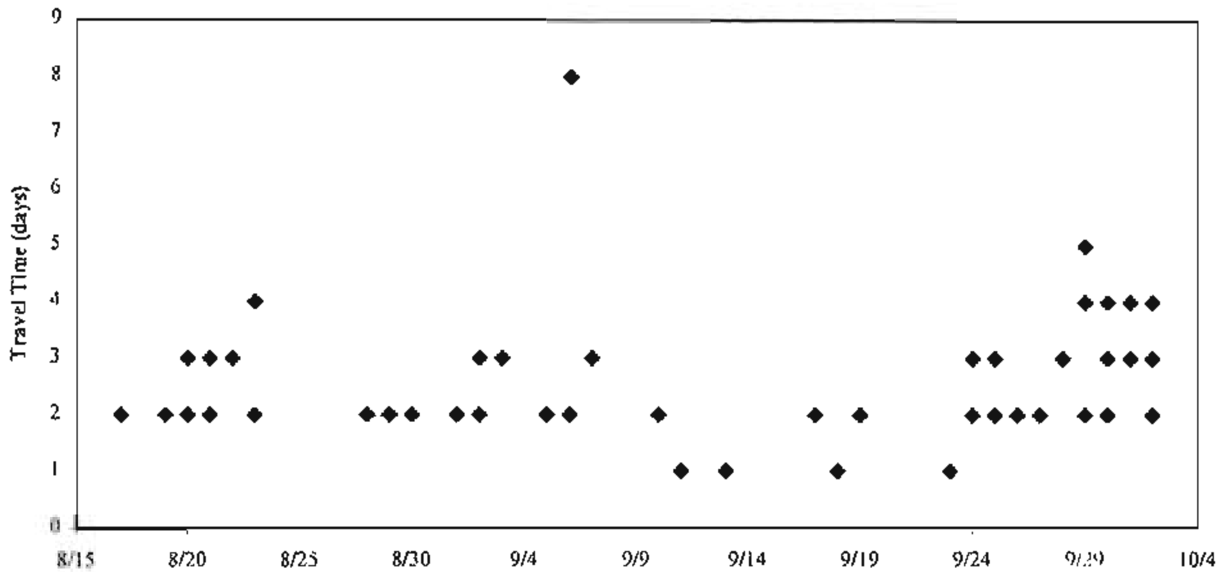

Figure 6. Travel time between the tag deployment and recovery wheels, for fall chum tagged between 16 August and 2 October, by date tagged, on the Tanana River, 1998.

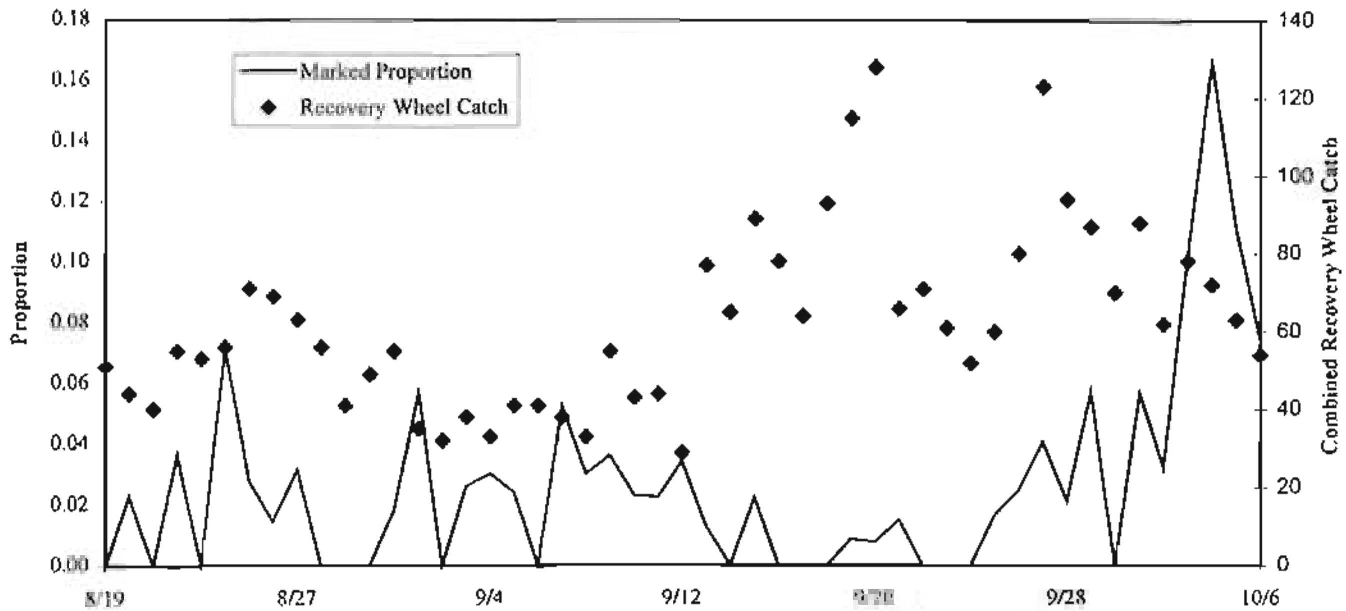

Figure 7. Daily marked proportion (proportion of recovery wheel catch bearing tags) of fall chum salmon at both recovery wheels, Tanana River, 1998.

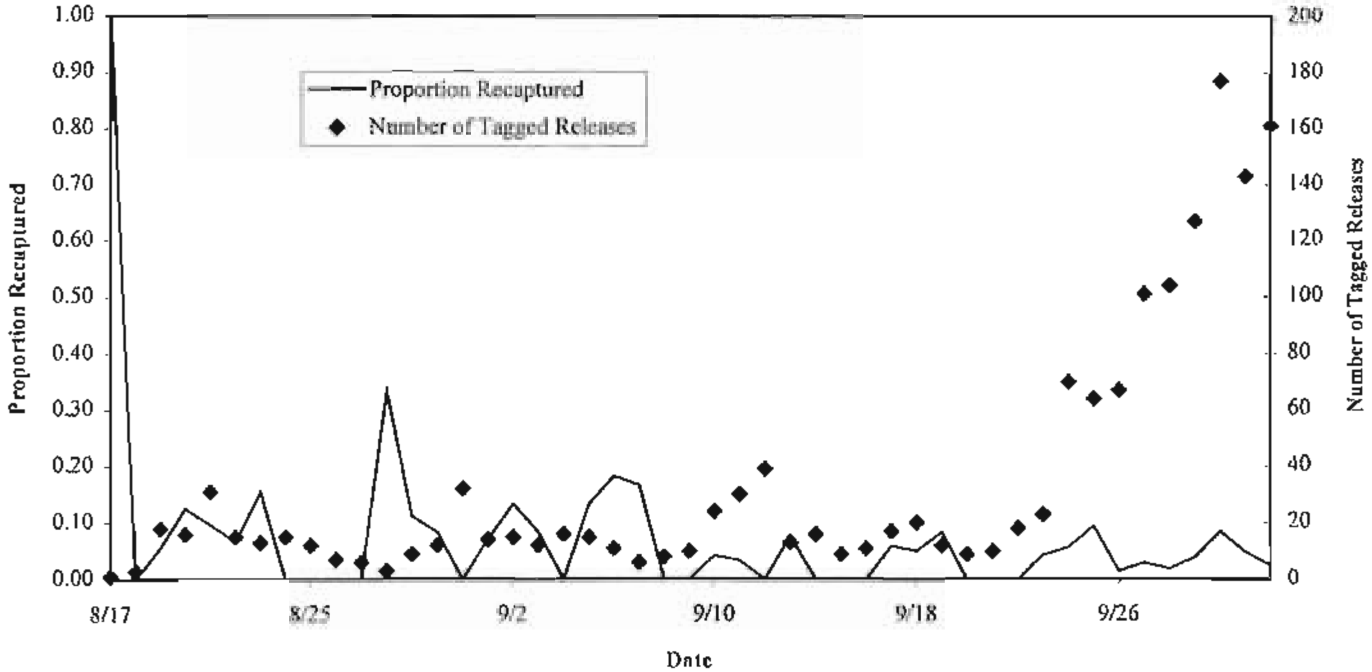

Figure 8. Daily proportion recaptured (proportion of tagged fish released at the tagging wheel that were subsequently recaptured at the recovery wheels) of fall chum salmon, Tanana River, 1998.

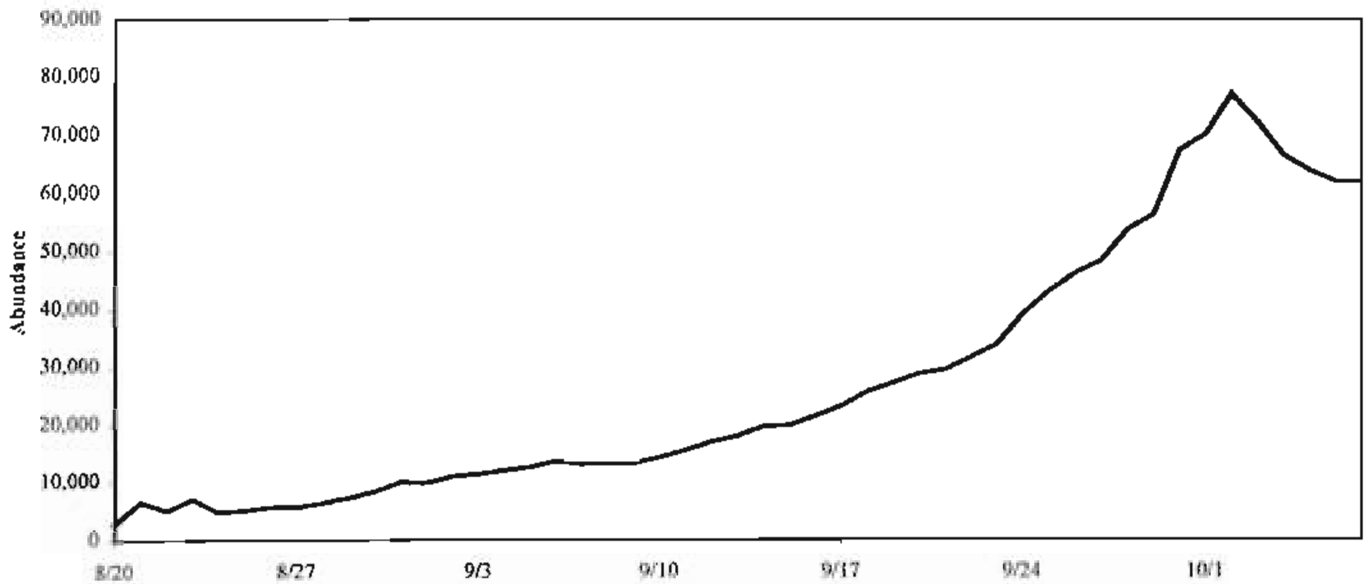

Figure 9. Abundance estimates of fall chum salmon using the Bailey mark-recapture model Tanana River, 1998.

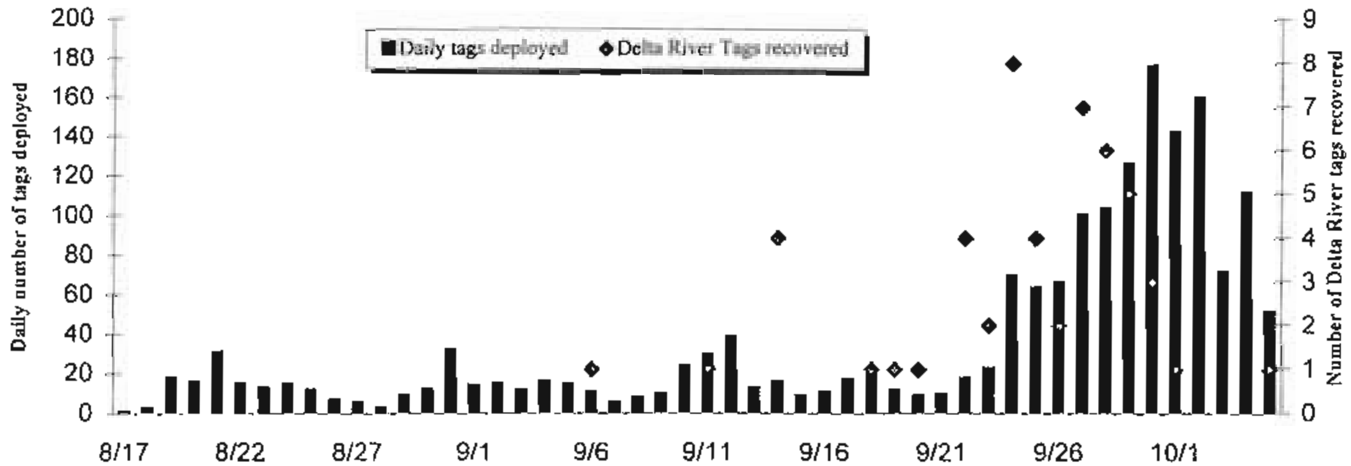

Figure 10. Number of tags recovered from fall chum salmon at the Delta River spawning grounds by date tagged in the Tanana River, 1998. The daily number of tags deployed is shown for comparison.

Appendix A.1. Daily effort and catch of fall chum salmon in the tagging wheel, Tanana River, 1998.

	Hours	Tagged			Not Tagged			Total			Cumulative
Date	Fished	Males	Females	Total	Males	Females	Total	Males	Females	Total	Catch
8/17	16	0	1	1	0	0	0	0	1	1	1
8/18	24	1	2	3	0	0	0	1	2	3	4
8/19	23	6	12	18	2	0	2	8	12	20	24
8/20	24	8	8	16	0	1	1	8	9	17	41
8/21	24	8	23	31	0	0	0	8	23	31	72
8/22	24	5	10	15	0	0	0	5	10	15	87
8/23	24	6	7	13	3	1	4	9	8	17	104
8/24	24	4	11	15	0	0	0	4	11	15	119
8/25	23	6	6	12	0	0	0	6	6	12	131
8/26	24	2	5	7	0	0	0	2	5	7	138
8/27	24	3	3	6	0	0	0	3	3	6	144
8/28	24	0	3	3	0	0	0	0	3	3	147
8/29	24	7	2	9	0	0	0	7	2	9	156
8/30	24	5	7	12	0	0	0	5	7	12	168
8/31	24	16	16	32	0	0	0	16	16	32	200
9/1	24	6	8	14	0	1	1	6	9	15	215
9/2	24	6	9	15	0	0	0	6	9	15	230
9/3	24	5	7	12	0	0	0	5	7	12	242
9/4	24	5	11	16	0	0	0	5	11	16	258
9/5	24	8	7	15	0	0	0	8	7	15	273
9/6	24	4	7	11	0	0	0	4	7	11	284
9/7	24	5	1	6	0	0	0	5	1	6	290
9/8	24	5	3	8	0	0	0	5	3	8	298
9/9	24	4	6	10	0	0	0	4	6	10	308
9/10	24	14	10	24	0	0	0	14	10	24	332
9/11	24	19	11	30	0	0	0	19	11	30	362
9/12	24	16	23	39	0	0	0	16	23	39	401
9/13	19	8	5	13	0	0	0	8	5	13	414
9/14	24	10	6	16	0	0	0	10	6	16	430
9/15	24	5	4	9	0	0	0	5	4	9	439
9/16	20	3	8	11	0	0	0	3	8	11	450
9/17	24	6	11	17	0	1	1	6	12	18	468
9/18	24	5	15	20	0	0	0	5	15	20	488
9/19	24	3	9	12	0	0	0	3	9	12	500
9/20	24	2	7	9	0	0	0	2	7	9	509
9/21	24	6	4	10	0	0	0	6	4	10	519
9/22	24	5	13	18	0	0	0	5	13	18	537
9/23	24	11	12	23	0	0	0	11	12	23	560
9/24	24	32	38	70	1	1	2	33	39	72	632
9/25	24	30	34	64	0	1	1	30	35	65	697
9/26	24	29	38	67	0	0	0	29	38	67	764
9/27	24	44	57	101	1	0	1	45	57	102	866
9/28	24	43	61	104	0	0	0	43	61	104	970
9/29	25	61	66	127	0	0	0	61	66	127	1097
9/30	24	73	104	177	0	0	0	73	104	177	1274
10/1	24	68	75	143	0	0	0	68	75	143	1417
10/2	24	60	101	161	0	0	0	60	101	161	1578
10/3	24	26	46	72	0	0	0	26	46	72	1650
10/4	24	39	73	112	0	0	0	39	73	112	1762
10/5	18	21	31	52	0	0	0	21	31	52	1814
Total		764	1037	1801	7	6	13	771	1043	1814	

Appendix B.1. Daily effort and catch of tagged and unmarked fall chum salmon in the right-bank recovery wheel, Tanana River, 1998.

	Hours	Tagged			Not Tagged			Total			Cumulative
Date	Fished	Males	Females	Total	Males	Females	Total	Males	Females	Total	Catch
8/16	24	0	0	0	15	18	33	15	18	33	33
8/17	24	0	0	0	12	14	26	12	14	26	59
8/18	24	0	0	0	4	8	12	4	8	12	71
8/19	24	0	0	0	5	6	11	5	6	11	82
8/20	24	1	0	1	4	5	9	4	5	9	91
8/21	24	0	0	0	8	8	16	8	8	16	107
8/22	24	0	1	1	17	14	31	17	14	31	138
8/23	24	0	0	0	10	11	21	10	11	21	159
8/24	24	2	2	4	11	8	19	13	10	23	182
8/25	24	1	1	2	18	18	36	19	19	38	220
8/26	24	0	0	0	19	19	38	19	19	38	258
8/27	24	0	0	0	16	24	40	16	24	40	298
8/28	24	0	0	0	12	10	22	12	10	22	320
8/29	24	0	0	0	9	8	17	9	8	17	337
8/30	24	0	0	0	13	21	34	13	21	34	371
8/31	24	0	1	1	13	12	25	13	13	26	397
9/1	20	0	0	0	4	5	9	4	5	9	406
9/2	24	0	0	0	13	12	25	13	12	25	431
9/3	25	0	1	1	8	11	19	8	12	20	451
9/4	22	0	1	1	10	8	18	10	9	19	470
9/5	24	0	1	1	12	13	25	12	14	26	496
9/6	25	0	0	0	8	15	23	8	15	23	519
9/7	24	0	1	1	10	15	25	10	16	26	545
9/8	24	0	0	0	7	6	13	7	6	13	558
9/9	24	1	1	2	19	14	33	20	15	35	593
9/10	20	0	1	1	8	6	14	8	7	15	608
9/11	20	0	0	0	9	11	20	9	11	20	628
9/12	24	0	0	0	3	3	6	3	3	6	634
9/13	24	0	0	0	18	19	37	18	19	37	671
9/14	24	0	0	0	15	12	27	15	12	27	698
9/15	24	1	0	1	18	19	37	19	19	38	736
9/16	24	0	0	0	12	13	25	12	13	25	761
9/17	24	0	0	0	1	9	10	1	9	10	771
9/18	24	0	0	0	14	19	33	14	19	33	804
9/19	24	1	0	1	20	17	37	21	17	38	842
9/20	24	0	1	1	14	16	30	14	17	31	873
9/21	24	0	0	0	12	13	25	12	13	25	898
9/22	24	0	0	0	10	14	24	10	14	24	922
9/23	24	0	0	0	4	13	17	4	13	17	939
9/24	24	0	0	0	4	11	15	4	11	15	954
9/25	24	0	0	0	5	6	11	5	6	11	965
9/26	24	0	0	0	7	8	15	7	8	15	980
9/27	24	0	0	0	12	22	34	12	22	34	1014
9/28	24	0	0	0	23	18	41	23	18	41	1055
9/29	24	1	0	1	10	20	30	11	20	31	1086
9/30	24	0	0	0	13	10	23	13	10	23	1109
10/1	24	0	1	1	12	16	28	12	17	29	1138
10/2	24	0	0	0	7	17	24	7	17	24	1162
10/3	24	2	2	4	5	15	20	7	17	24	1186
10/4	21	1	4	5	13	17	30	14	21	35	1221
10/5	24	0	2	2	9	20	29	9	22	31	1252
10/6	12	0	1	1	6	23	29	6	24	30	1282
Total		11	22	33	561	690	1251	571	711	1282	

Appendix B.2. Daily effort and catch of tagged and unmarked fall chum salmon in the left-bank recovery wheel, Tanana River, 1998.

	Hours	Tagged			Not Tagged			Total			Cumulative
Date	Fished	Males	Females	Total	Males	Females	Total	Males	Females	Total	Catch
8/16	23	0	0	0	11	12	23	11	12	23	23
8/17	24	0	0	0	20	26	46	20	26	46	69
8/18	24	0	0	0	20	29	49	20	29	49	118
8/19	24	0	0	0	17	23	40	17	23	40	158
8/20	24	0	0	0	13	22	35	13	22	35	193
8/21	24	0	0	0	13	11	24	13	11	24	217
8/22	24	0	1	1	12	11	23	12	12	24	241
8/23	24	0	0	0	12	20	32	12	20	32	273
8/24	24	0	0	0	16	17	33	16	17	33	306
8/25	24	0	0	0	9	24	33	9	24	33	339
8/26	24	0	1	1	13	17	30	13	18	31	370
8/27	24	1	1	2	13	8	21	14	9	23	393
8/28	24	0	0	0	13	21	34	13	21	34	427
8/29	24	0	0	0	9	15	24	9	15	24	451
8/30	24	0	0	0	9	6	15	9	6	15	466
8/31	24	0	0	0	14	15	29	14	15	29	495
9/1	24	1	1	2	9	15	24	10	16	26	521
9/2	24	0	0	0	4	3	7	4	3	7	528
9/3	24	0	0	0	8	10	18	8	10	18	546
9/4	25	0	0	0	6	8	14	6	8	14	560
9/5	23	0	0	0	8	7	15	8	7	15	575
9/6	25	0	0	0	7	11	18	7	11	18	593
9/7	24	1	0	1	8	3	11	9	3	12	605
9/8	25	0	1	1	7	12	19	7	13	20	625
9/9	24	0	0	0	9	11	20	9	11	20	645
9/10	24	0	0	0	10	18	28	10	18	28	673
9/11	24	1	0	1	10	13	23	11	13	24	697
9/12	24	0	1	1	11	11	22	11	12	23	720
9/13	24	1	0	1	17	22	39	18	22	40	760
9/14	24	0	0	0	17	21	38	17	21	38	798
9/15	24	1	0	1	20	30	50	21	30	51	849
9/16	24	0	0	0	24	29	53	24	29	53	902
9/17	24	0	0	0	26	28	54	26	28	54	956
9/18	24	0	0	0	24	36	60	24	36	60	1016
9/19	24	0	0	0	31	46	77	31	46	77	1093
9/20	24	0	0	0	35	62	97	35	62	97	1190
9/21	24	1	0	1	11	29	40	12	29	41	1231
9/22	24	0	0	0	18	29	47	18	29	47	1278
9/23	24	0	0	0	23	21	44	23	21	44	1322
9/24	24	0	0	0	12	25	37	12	25	37	1359
9/25	24	1	0	1	24	24	48	25	24	49	1408
9/26	24	0	2	2	29	34	63	29	36	65	1473
9/27	24	3	2	5	38	46	84	41	48	89	1562
9/28	24	2	0	2	15	36	51	17	36	53	1615
9/29	24	1	3	4	27	25	52	28	28	56	1671
9/30	24	0	0	0	18	29	47	18	29	47	1718
10/1	24	4	0	4	14	41	55	18	41	59	1777
10/2	24	2	0	2	12	24	36	14	24	38	1815
10/3	24	2	2	4	20	30	50	22	32	54	1869
10/4	24	2	5	7	11	19	30	13	24	37	1906
10/5	24	3	2	5	11	16	27	14	18	32	1938
10/6	14	3	0	3	6	15	21	9	15	24	1962
Total		30	22	52	794	1116	1910	824	1138	1962	